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Interactive and Graphic Techniques for Computer-Aided Route Selection

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The development of the GCARS system of computer-aided highway corridor selection and its application in an environmental impact analysis in western New York State are discussed. Current versions of GCARS use an efficient minimum-path algorithm to generate route alternatives by accessing digital data bores that define engineering, socioeconomic, and environmental factors. These data bores are manipulated interactively by a companion computer system called GMAPS. The GMAPS and GCARS systems clearly show the desirability of low-cost, easy-to-operate, interactive systems for regional transportation planning studies. Graphical and statistical displays are essential, and a variety of black-and-white and color display options have been developed. Because each product has unique cost-benefit characteristics, the choice of display type must be matched to audience needs and costs of production. The use of GMAPS-GCARS in a corridor-selection study for a 160-km (100-mile) four-lane highway in western New York is described. The study shows a marked reduction in planning time at no increase in planning costs. This suggests that more widespread use of computer-aided analysis systems may result in large savings during periods of rapid inflation.

The process of highway corridor selection was revolutionized by the passage in 1969 of the National Environmental Policy Act (NEPA). Today, the "best" location for a transportation system is no longer necessarily the one that produces the greatest reduction in travel time or the one that results in the lowest capital or user costs. Rather, it is the design that yields the highest social return on the transportation investment and reconciles most effectively the conflicting interests of the various groups affected by the proposal. Location engineers are faced with analyzing larger numbers of interacting and conflicting location factors. Decisions must be made on the number of factors and the relative importance of all factors. Sensitivity analyses are required.

The digital computer offers an efficient means of applying models that describe the regional environment to the task of corridor selection. This requires the integration of a wide variety of digital models, each of which defines some component of the regional environment. The success of such applications depends on many factors, the most critical of which are

1. Efficient, low-cost methods of data entry, checking, and display;
2. The ability to accept and manipulate many kinds of data;
3. Easy-to-use, preferably interactive, methods of determining which data are available and for manipulating such data; and
4. Statistical and graphical display methods to allow for rapid assimilation and assessment of data by the system user.

This paper discusses the design philosophy that underlies one such system, the Generalized Computer-Aided Route Selection (GCARS) system. GCARS has been under development for at least 10 years (1); however, the development of smaller, economical interactive computers over the past 4 or 5 years, accompanied by recent development of low-cost graphical display hardware, has greatly assisted the transition of research concepts into a practical, commercially viable system. The integration of these new hardware capabilities with appropriate software design is illustrated in this paper by a recent application of GCARS to a highway location study in New York State.

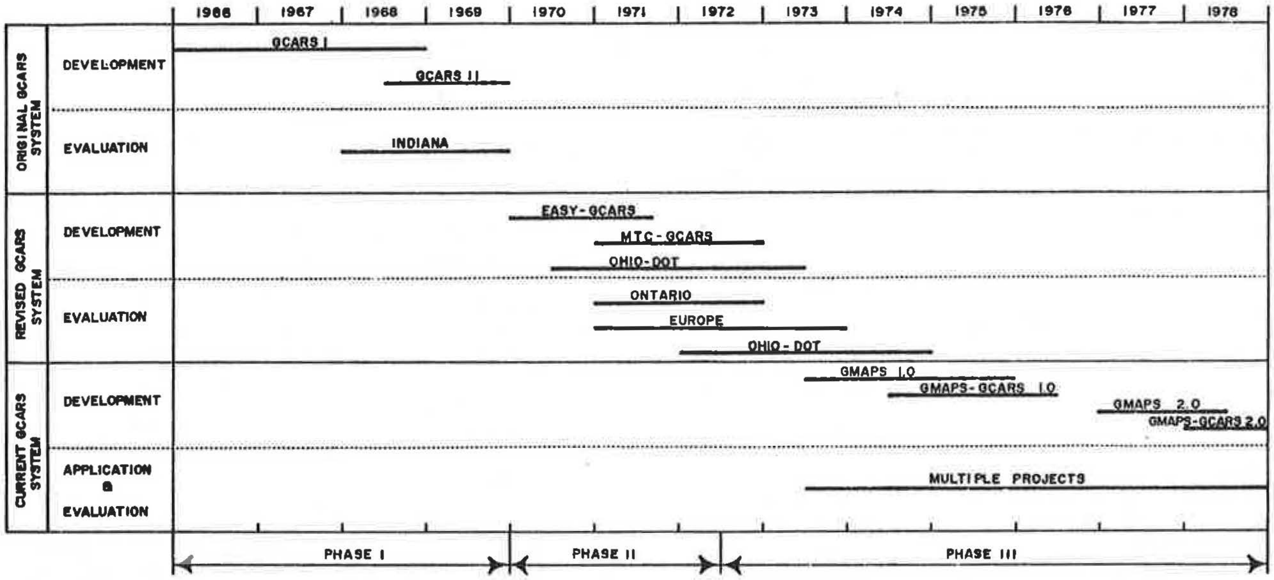
SYSTEM DESIGN GOALS

Development of the GCARS system has been guided from the beginning by six design goals:

1. The system should be machine independent; that is, it should be easily implemented on a variety of computers built by different manufacturers.
2. The system should be economical to use. This goal was interpreted as modest computer core-storage requirements and short calculation times.
3. The system should provide effective and convenient methods of person-machine information interchanges. This goal appeared necessary in order to allow engineers to apply their decision-making capabilities.
4. The system should have sufficient flexibility to allow (a) suitable quantitative measures of all pertinent factors and (b) the analysis of pertinent factors alone or in varying combinations.
5. The system should have sensitivity to the factors being analyzed and include techniques of ranking and discriminating between the alternatives generated.
6. The system should be generally compatible with existing planning methodology and available, more detailed design systems in terms of resolution and data requirements.

Obviously, these design goals represent the ideal case. It was recognized that conflicts within and among these

Figure 1. Chronology of GMAPS-GCARS system development.



goals might prevent their complete achievement. Nevertheless, they did represent, and continue to represent, an ultimate yardstick by which all computer-aided planning systems should be measured.

HISTORICAL DEVELOPMENT OF THE GCARS SYSTEM

A recent companion paper (1) traces the development of the GCARS system from its first development in 1966 to the present. Only a brief summary is included here to illustrate the effects of improvements in computer hardware. As Figure 1 shows, GCARS development can be divided into three main phases, each of which contains a development-evaluation cycle.

Phase 1: 1966-1969

During phase 1 of GCARS development, two research systems—called GCARS I and GCARS II—were developed and evaluated. GCARS I was used in a batch processing environment on Control Data Corporation (CDC) equipment. The programs stored environmental conditions as matrices no larger than 50x50 cells and located routes by performing minimum-path analysis on these matrices. The minimum-path algorithm was adapted from Martin's FORTRAN coding of the British Road Research Laboratory algorithms (2). Both GCARS I and GCARS II were able to generate about one alternative per minute of control processing unit (CPU) time on the largest-sized matrix (2500 cells) while using only moderate core storage (around 50K words on the CDC 6600).

The GCARS I design was tested at two areas (3-5). Demonstrations were subsequently given for practicing highway location engineers. In view of the favorable response, it was decided to present the GCARS system to a broader group of engineers and students and obtain their evaluations.

In 1969, Purdue University developed an interactive computing system, called PROCSY, which allowed a large number of remote terminals to create, submit, and retrieve jobs. A series of specialized computer programs was prepared that allowed users to access the GCARS I programs and data sets via the PROCSY system. This series of programs was called GCARS II (6).

GCARS II proved to be an ideal teaching tool. After 10 or 15 min of instruction, engineers attending a short course were able to use the system to submit their job requests. The chief advantage of the system was its interactive nature: During the submission procedure, the terminal prompted the engineer with a series of questions, to which the engineer responded and so prepared a job request.

Phase 2: 1970-1973

In phase 2, the earlier versions of GCARS I were modified to work on IBM 360 systems, where they used about 165K bytes of storage. An extensive series of evaluations was made in Canada, the United States, and Europe. During this period, GCARS evolved from a purely research tool into an instructional one. This required methods by which larger numbers of persons, some of whom had little or no background in computer use, could interact with the programs.

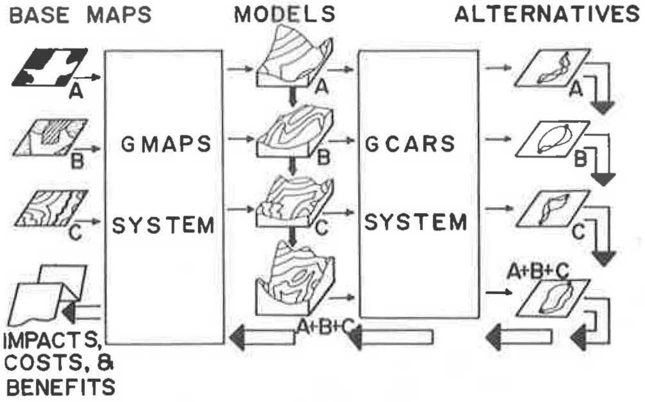
Ideally, conversational, interactive methods would be used. The advantages of such capabilities had been clearly demonstrated by GCARS II. But few conversational systems were available, and so it was decided to develop a simplified request system that could be submitted as a series of batch jobs in the regular job stream. Since the cards had to be punched by inexperienced persons, it was desirable that the cards be as simple and flexible as possible. Accordingly, a FORTRAN program called EASY—which used the NAMELIST statement available in IBM FORTRAN—was developed. Each student was supplied with a set of job-control-language cards and submission instructions.

Although it was not as easy to use as the GCARS II system because the interactive features of GCARS II were lost, EASY-GCARS proved to be relatively easy to use for people who had little previous contact with computers. EASY-GCARS was used successfully by students at the University of Toronto and by engineers attending a short course in London, England (in London, about 95 percent of the jobs submitted ran successfully). EASY-GCARS was also used on a number of demonstration projects in Ontario (7).

Phase 3: 1973-1979

A totally new system of programs called GMAPS-GCARS, developed beginning in 1973, incorporates many changes shown to be desirable by the previous work. In these new systems, the model-building steps were separated from those of corridor selection so that the GMAPS (Generalized Map Analysis Planning System) programs were responsible for model building and a new GCARS program suite was

Figure 2. Concept of GMAPS-GCARS.



responsible for corridor selection (see Figure 2).

The GMAPS-GCARS programs are designed to use interactive terminal dialogs in time-sharing environments. Initial development was done on DEC System-10 computers, but later installations were made on CDC CYBER computers (operating under the KRONOS and NOS time-sharing systems), IBM 370/168 computers (operating under TSO), and PDP 11/34 and PDP 11/70 computers (operating under RSTS/E).

GMAPS-GCARS SYSTEM

Basic Concept

The basic concept of GCARS from its inception was the application of minimum-path analysis techniques to "numerical cost models" so as to generate a series of ranked alternatives. This concept is shown in Figure 2, where the various numerical cost models are shown as solid three-dimensional surfaces. In actual practice, they are stored as matrices within the computer. This concept has been described by some users as "linear programming with maps".

Desirable routes will follow the "valleys" across such cost models. The most desirable route combines directness and "low elevations" so as to obtain the lowest total cost. Less desirable routes follow other valleys and "pass over" the intervening high-cost areas. Sometimes such alternatives are shorter than the first choice and, although they have a higher cost per unit length, may be more desirable. The various choices should thus be compared in terms of overall length and total cost.

Minimum-path analysis can be used to locate such valleys and alternate routes. A grid network is formed from the cost-models matrix by joining all nodes. Each link is then assigned the cost of traversing it. Thus, minimum-path analysis will discover the optimal path. Ayad (8) has proposed a method of generating a series of significantly different ranked alternative choices. If the central links that form the optimal route are raised in value, their reuse will be inhibited and reanalyzing the revised network will produce a second minimum—a "second-best" alternative. Repeating the process will allow the generation of a ranked series of alternatives. Comparison of these paths allows for sensitivity analyses and leads naturally into impact assessments.

Figure 2 also shows that models for several factors can be superimposed to produce models that represent any desired combination of factors. This model-building component was fairly simplistic in the original GCARS I system, but it is now a fairly large and complex task that is assigned to the GMAPS system programs (Figure 2).

Goal achievement and cost statistics are important analytic tools in comparing the alternative corridors generated by GCARS. This capability has also been enhanced in the latest GMAPS-GCARS versions. As Figure 2 shows, the production of impact, cost, and benefit statistics is performed largely by GMAPS, which uses data supplied by GCARS along with its own model data.

GMAPS Programs

The GMAPS programs were originally developed to meet the needs of environmental assessment. It was recognized that relatively sophisticated capabilities for data-base manipulation were required but that these must be understandable to persons who had little experience with computers. At the same time, the system had to be capable of comprehensive quantitative analyses, accept a variety of data, and operate economically (9).

An interactive cellular mapping system that uses composite computer mapping techniques was chosen. A modified cellular storage concept was selected because it lent itself to economical data-entry procedures that required no specialized equipment. A method of "cellular strings" was used to economically convert existing mapped data to machine-processable code (9). The GMAPS programs also accept other optional data sources, including census data tapes and LANDSAT digital imagery classifications.

All steps of the GMAPS process—data entry, checking, cataloging, manipulation, and display—are performed as a series of interactive, self-prompting operations. This makes GMAPS very attractive to use, for the following reasons:

1. The programs are self-prompting. They ask a sequence of questions to which the user responds and by which the user defines the operations and sequence of operations he or she wishes to perform.
2. The programs allow the user to verify and correct commands so that meaningless operations are eliminated.
3. The system is easily used by the layperson.
4. The time-sharing concept gives the user economical access to a high-capacity computer.

The composite computer mapping techniques incorporated into GMAPS represent a powerful extension of the traditional planning method of overlaying tonal transparencies and visually selecting optimum areas (10-12). In GMAPS, the overlaying of tonal transparencies is replaced by the algebraic combination of two or more matrices whose elements have values that correspond to the gray-tone densities. GMAPS allows both arithmetic and logical compositing procedures. Arithmetic compositing is a simple extension of tonal overlay procedures but allows much more varied analyses by using combinations of addition, subtraction, multiplication, and division in conjunction with the ability to weight some components more heavily than others. Logical compositing is even more flexible because it allows a detailed examination of the conditions within each map cell and the creation of a resulting composite map that reflects these conditions.

The GMAPS programs include a variety of display capabilities that reflect the diversity of user needs and the economics of the applications. At one extreme is the capability to display scaled-down maps, or selected "window areas" of maps at full scale, on the standard 80-column, 30-characters/s terminal. Such displays are obviously limited by terminal speed and size; however, they form an indispensable quick-look capability for a user who is working late at night or in an isolated location.

The standard line printer, set at 3 lines/cm (8 lines/in), is the most commonly used display device. The printer is economical because it is readily available, rapid, and capable of producing large-scale displays. This is useful for data-checking purposes. The line printer gives a 10-level (maximum) gray-tone display by using 2-level overprinting; aesthetic quality is further enhanced by adding titles in 2.5-cm (1-in) high block letters (such as those used for banner pages on most systems), legends, north arrows, and bar scales as appropriate.

GMAPS has been used to generate more sophisticated displays where specialized equipment and needs existed. Products include cathode-ray-tube (CRT) and electrostatic plotter displays, direct productions of 35-mm color slides, and hard-copy color displays by several techniques. Interface programs are required to convert the standard GMAPS data bases to the plotting standards of these specific devices.

GCARS Programs

An entirely new sequence of GCARS programs was developed to interface with the GMAPS data bases and incorporate all the suggested improvements. Because GCARS contains a substantial computation cycle, it operates in a mixed foreground-background manner. Job-request generation is performed interactively in a self-prompting format. The computations are then performed in a background mode, which frees the terminal and the operator to perform other tasks.

An entirely new minimum-path algorithm is incorporated into GCARS. This algorithm is 10-20 times more efficient than the Martin algorithm (2) originally used. The new algorithm has several other advantages: It allows movement along diagonal directions, core requirements are drastically reduced, and computational efficiency is a linear function the length of the corridor.

The results of a GCARS analysis can be displayed in a variety of ways that are selected by the operator in an interactive fashion. The options include maps of the routes—either on their own or superimposed on appropriate gray-tone cellular maps—and statistical summaries that give the user the basic path totals, lengths, and comparisons needed to make assessments. The planner is also assisted in evaluating goal achievement and cost criteria. Achievement can be measured by comparing each alternative corridor generated for some composite suite of goals with the optimal corridors produced by evaluating each goal dependently. Cost evaluations are made by overlaying the generated choices on a construction cost model.

SOUTHERN TIER EXPRESSWAY STUDY

In 1975-1976, the GMAPS-GCARS systems were used to aid in the environmental impact analysis of about 160 km (100 miles) of new four-lane highway, the Southern Tier Expressway in extreme western New York and Pennsylvania (see Figure 3). The impact assessment included a description of transportation and transportation-related problems, resulting transportation needs, specific project objectives, transportation location alternatives, and an evaluation of the potential impact associated with each alternative. The scope of the project was therefore quite broad; it extended considerably beyond the capabilities of computer-aided assessment embodied in GMAPS-GCARS. Nevertheless, the GMAPS-GCARS systems played a significant role in the analysis of location alternatives and in the assessment of each.

To develop as comprehensive and complete a group of highway alternatives as possible, the GMAPS-GCARS analyses were checked by an independently conducted conventional transportation analysis. The combination of these two procedures provided as objective a group of alternate corridors as possible.

It was important that potential highway corridors selected for detailed cost evaluation and environmental impact assessment be identified on the basis of social, economic, and ecological considerations as well as engineering feasibility. A rectangular detailed study area was selected for the GMAPS-GCARS analyses (Figure 3). This area was chosen for a number of reasons. Important considerations were that it encompassed all previously expressed corridor preferences, it incorporated I-90 and existing Southern Tier Expressway segments, it enabled all reasonable alternative corridors to be considered by embracing an area sufficiently broad to allow for any practical corridor circuity, and it was the area that earlier study had shown to be of greatest impact, influence, and interest with reference to the Southern Tier Expressway.

Corridor alternatives were evaluated by two methods: a computer-aided method that involved the GMAPS-GCARS programs and an independently conducted conventional transportation analysis. Data for 22 baseline maps (see Table 1) that described a variety of engineering, cultural, economic, and environmental factors were plotted on a 1:62 500-scale base. These data were converted to a cellular matrix representation and entered into computer storage via the GMAPS programs. The resolution of this digital data was 3.16 hm^2 (7.8 acres), or a rectangle (cell) 198x158 m (650x520 ft). A total of almost 180 000 cells were required.

As Table 1 illustrates, the GMAPS process produced a series of derivative, determinant, and ultimately composite models that showed the desirability of highway corridor location based on (a) engineering feasibility, (b) improving social and economic conditions, and (c) environmental impact. These three composite models were calibrated and approved and then combined in various ratios to produce a sequence of total highway corridor feasibility models.

Figure 4 shows the corridor alternatives generated by GCARS for each of the three basic composite models and for one combination of these models. After a very large number of such analyses were run, a general pattern emerged in which five major alternatives dominated. These results were synthesized with those obtained by conventional techniques, and 12 detailed alternative corridor locations were selected by using various combinations of 31 sections.

CURRENT RESEARCH AND DEVELOPMENT ACTIVITY

The current versions of GMAPS-GCARS have evolved over a decade, but they are not static products and further developments are under way. Based on experience to date, the use of cellular interactive geoinformation systems offers an attractive mix of cost efficiency, flexibility of display, and analytic capability that is most appropriate during the early project planning stages. Current research and development activities are focused on three areas: automated data entry, expanded analytic capabilities, and color display capability.

Automated Data Entry

The need for realistic baseline data has been recognized from the beginning. Development of GMAPS greatly improved data collection and resolution capabilities, but further improvements are needed.

The use of direct television video scanning of basemaps and the subsequent analog-to-digital conversion of these signals appear to offer a breakthrough in data gathering. In a recent paper, Chu and Anuta (13) describe experiments in automatic color map digitization. Early incorporation of automatic data-entry methods into GMAPS is anticipated.

Expanded Analytic Capabilities

Work is already under way to add new analytic capabilities to GMAPS. Contouring and proximity functions are being tested, and a suite of multivariate statistical functions is being developed. These will require additional file handling and cataloging capabilities and will enhance the ability of GMAPS (and GCARS) to interact with air- and water-pollution models, socioeconomic analyses, and similar simulation models.

Color Display Capability

GMAPS has already been interfaced with two color display systems. At Los Alamos Scientific Laboratory, color 35-mm slides were produced by using a modified FR-80 film plotting device. More recently, hard-copy color dis-

Figure 3. Southern Tier Expressway study area.

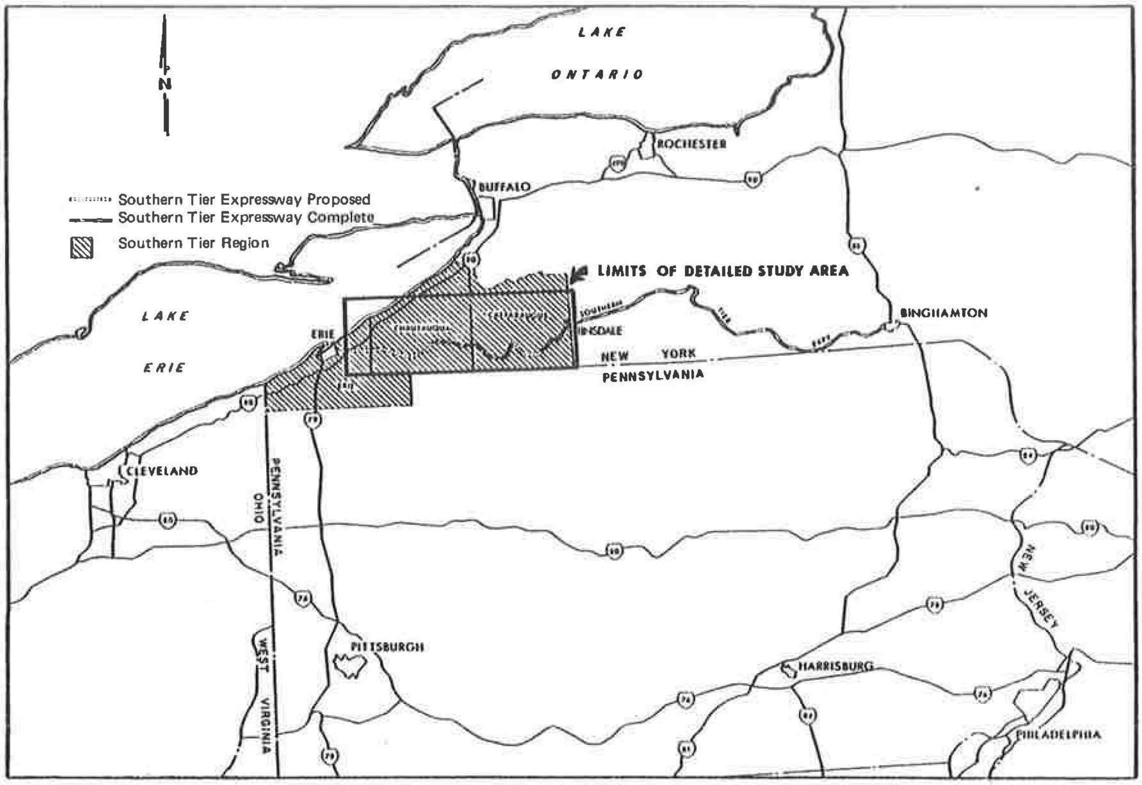
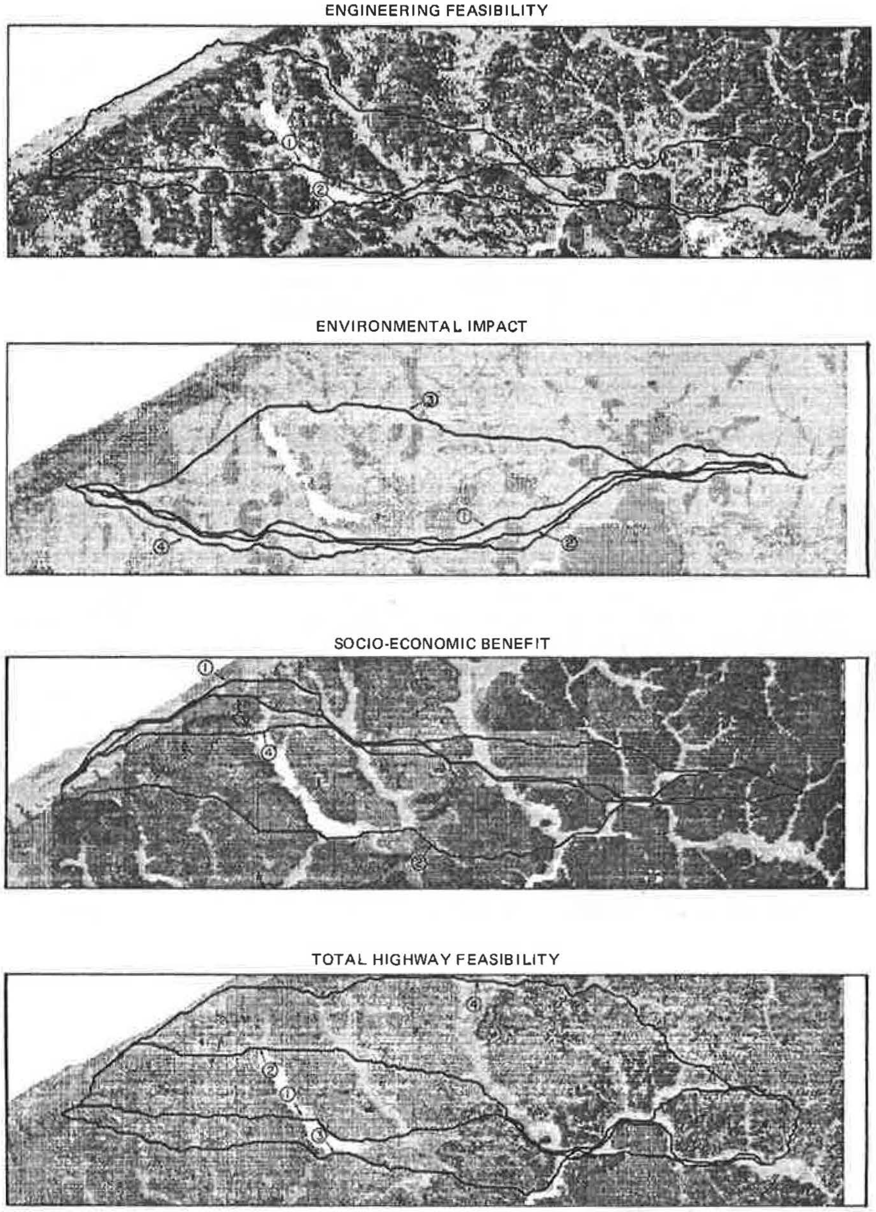


Table 1. Baseline, derivative, determinant, and composite data products for Southern Tier Expressway project.

Baseline	Derivative	Determinant	Composite
Accessibility Land use Pipelines and transmission lines Existing transportation Landforms Soil types Slope Mean annual rainfall Mean annual snowfall Water bodies	Land values Erosion potential Existing maintenance conditions Geotechnical factors Drainage potential	Cost Land acquisition Construction Maintenance	Feasibility of highway sites
Ecologically sensitive areas Groundwater yield Water bodies Recreation Land use Landforms Slope Agricultural districts Areas of highway needs Soil types Historical, archeological, and cultural sites Population density Level of service	Water quality sensitivity Erosion potential Vegetation types Scenic sensitivity Agricultural productivity Noise sensitivity Air quality sensitivity	Impact Ecological Land use Energy use Cultural and social	Environmental impact
Outmigration Unemployment Land use Average family income Recreation Population density Trip attraction Accessibility Landforms Mean annual rainfall Mean annual snowfall Level of service	Areas of economic need Institutions, recreation, and commercial areas Growth centers Areas of highway need User costs Safety	Stimulate regional economy Improve accessibility User benefits	Social and economic benefits



ENGINEERING FEASIBILITY

ENVIRONMENTAL IMPACT

SOCIO-ECONOMIC BENEFIT

TOTAL HIGHWAY FEASIBILITY

Figure 4. Four GCARS alternative corridor analyses.

plays were produced on an APPLICON color ink plotter. Interface programs are being refined that will allow the production of displays that include titles; placement of legends, north arrows, and bar scales; the plotting of entire maps or selected portions of them; and the overlaying of selected political or geographic boundaries.

CONCLUSIONS

It seems probable that computer-aided planning systems that incorporate at least some of the GMAPS-GCARS system elements will have a large role to play in future planning methodology. Computer-aided systems are particularly attractive in analyzing complex or ambiguous factor interactions, and the trend to greater complexity and ambiguity of location factors seems well established. Recent studies have shown that, in the highway field at least, early project planning is constrained by environmental assessment considerations. Although new highway construction appears to be on the wane, demand for new electrical transmission lines and for oil, gas, or coal slurry pipelines seems to be on the rise. The location analyses for these transportation forms can be easily handled by the GMAPS-GCARS systems.

The GMAPS-GCARS programs substantially reduced the time required for the Southern Tier Expressway study. In spite of the controversy and complexity of this project, the draft environmental impact statement (EIS) was prepared in one year rather than in the two years normally anticipated. The final EIS received final approval in just over two years from project initiation rather than in the more normal three years.

Such time savings translate into large economic savings, especially when the analyses are performed at costs lower than or equal to those of the more traditional manual methods. In the Southern Tier Expressway study, the entire GMAPS-GCARS analysis involved about $20 000 of computer time, and each 300-m (1000-ft) wide GCARS corridor cost about $0.30/km ($0.50/mile) to generate. More recent versions of GMAPS cost even less to use because they can operate in as little as 25K words on a PDP-11.

The key to a successful system such as GMAPS-GCARS lies in its ability to (a) operate interactively; (b) perform analytic functions economically at a precision appropriate to the project planning level; (c) accept data rapidly and economically, possibly by way of video digitizing; and (d) display results graphically and statistically in a variety of formats.

For public presentations, color displays are most effective. They appear "familiar" to lay people and can illustrate points vividly without appearing "automated". A substantial segment of the population appears to view computer-generated products as subject to manipulation. Color display products appear to partially allay such fears.

The successful application of GMAPS-GCARS to the Southern Tier Expressway case points to the increased importance of such systems in future planning for all modes of transportation. This prediction of increased importance and acceptance is based on current trends, namely

1. The availability of good-quality, computer-processable data banks;
2. The development of "companion" computer programs to handle other aspects of transportation planning and design;
3. The increased availability of interactive computer systems;
4. The widespread installation of time-sharing computer networks supported by minicomputers; and
5. The availability of newer, cheaper, and yet more powerful units that are capable of producing color and black-and-white products suitable for projection or printing via offset printing techniques.

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Improved Highway Safety Through Interactive Graphics

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The Centralized Local Accident Surveillance System (CLASS), which is being developed by the Traffic and Safety Division of the New York State Department of Transportation to meet federal requirements and to improve highway safety for New York motorists, is described. CLASS includes information about each of the almost 600 000 accidents that occur annually on the 172 000 km (107 000 miles) of public roads in New York and is primarily geared toward meeting the needs of local safety officials, who have responsibility for 148 000 of these kilometers (92 000 miles). The major elements of CLASS are (a) an accident-site-location map produced by interactive graphics techniques and a "link-node" coding scheme, (b) a data base that contains highway information and accident data oriented to the link-node system, and (c) a software system that allows data base information to be accessed, summarized, and analyzed and permits communication between the graphic and nongraphic files. The advantage of a highway safety program based on the concept of interactive graphics is demonstrated.

The New York State Department of Transportation (NYSDOT) is actively involved in aiding local governments to carry out their safety responsibilities on the highways under their jurisdiction. This involvement begins with the provision of the accident data and analytic techniques that are necessary to identify where safety efforts should be aimed. The Centralized Local Accident Surveillance System (CLASS) will provide this local support.

CLASS is a computerized tool that provides three primary types of information to local officials: safety, highway inventory, and map. Each type of information will be discussed in more detail later in this paper. In brief, CLASS is a versatile system designed to meet local needs and provide current information.

In implementing this project, New York will be the first state to provide and analyze accident information for every public road within its boundaries. The project is also unique in that it uses direct computer interface between graphics and data files. The CLASS project, totally funded under the Section 402 Highway Safety Grant Program (Title 2, Surface Transportation Assistance Act of 1966, as amended), will provide a focal point from which a consistent, statewide highway safety improvement program can be implemented.